REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	2/8/96	Final (3/15/94 - 9/15/95)

4. TITLE AND SUBTITLE

MODELING OF THE ACOUSTIC PROPAGATION IN SHALLOW WATER OCEANIC REGIONS

5. FUNDING NUMBERS

G: N00014-94-1-0565

6. AUTHOR(S)

Stephan T. Grilli & Peter R. Stepanishen

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Department of Ocean Engineering
University of Rhode Island
Narragansett, RI 02882

8. PERFORMING ORGANIZATION REPORT NUMBER

None

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
Ocean Acoustic Division

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The long term goal of this work is to develop a numerical model for studying acoustic propagation in range and depth dependent shallow water environments, with inclusion of bottom effects. In this project, simplified two-dimensional models, both analytical and numerical, were developed to study the effect of complex (rigid) bottom topography on the acoustic propagation in an otherwise homogeneous water column. In both cases, a Boundary Integral Equation approach was used. Matching was specified along interface boundaries between the solution in the interior region, with irregular topography, and exterior constant depth radiation regions. Eigenfunction expansions of the solution were used in radiation region. Results were obtained for simple obstacles in an otherwise flat bottom (steps, rectangular obstacles, plus plane slopes and wedges). Using an impedance transfer matrix, the method can also solve problems for an arbitrary combination of steps and wedges.

14. SUBJECT TERMS

acoustic propagation; shallow water acoustics

15. NUMBER OF PAGES

7

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to ***stay within the lines*** to meet ***optical scanning requirements***.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	- Contract	PR	- Project
G	- Grant	TA	- Task
PE	- Program Element	WU	- Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."
DOE - See authorities.
NASA - See Handbook NHB 2200.2.
NTIS - Leave blank.

Block 12b. Distribution Code.

DOD - Leave blank.
DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
NASA - Leave blank.
NTIS - Leave blank.

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

Final Technical Report
Grant No.: N00014-94-1-0565

19960821 108

A) Header information

1. **Name of principal investigators :**

   (i) Stéphan Grilli, PI (Associate Professor, Dept. Ocean Engng., University of Rhode Island, Narragansett, RI 02882. Tel : (401) 874-6636. Fax : (401) 874-6837. Email : grilli@mistral.oce.uri.edu)

   (ii) Peter Stepanishen (Co-PI) (Professor, same address)

2. **Title of grant :** Modeling of the acoustic propagation in shallow water oceanic regions including effects of bottom geometry and sub-bottom propagation (3/15/94 to 9/15/95)

3. **Long term goal of the project :** To develop a numerical tool (model) for the study of acoustic propagation in a range and depth dependent shallow water environment, with inclusion of bottom effects (scattering and transmission).

4. **Category of research :** propagation (theory, modeling and, computations)

5. **Impact on S&T, or transition/integration :** The first limited numerical model developed in this project will make it possible both to understand and to qualitatively predict acoustic signals measured in some of the recent shallow water experiments (e.g., Badiey *et al.*, 1994). The new physical insight gained will help better select and define the important features and the best approach for a more general model, to be developed at a later stage, that will address the long term goals of this project.

6. **Relationship to other projects :** This project has used results from recent ONR supported in-situ experiments of shallow water acoustic propagation.

B) Narrative Documentation

1 Background

Emphasis is now put in the naval community towards problems of acoustic propagation in shallow water regions. Shallow water acoustic problems bring new challenges due to both the range and depth dependent environment (water stratification, complex bottom topography) and the propagation of acoustic waves into the bottom sediments. For various reasons, all

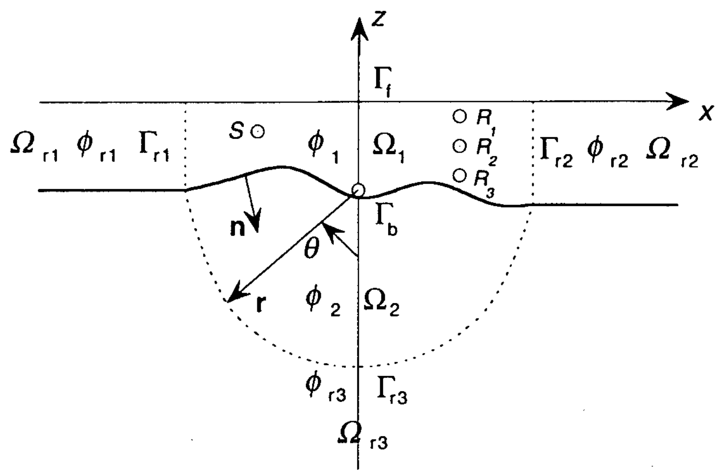

Figure 1: Typical configuration of computational domain for hybrid-BEM solution. Domain 1 has arbitrary geometry and is discretized by BEM. Domain 1 also features sources (S) and receivers (R). Domains $r1$, $r2$, and $r3$ are radiation domains, in the water or in the bottom.

traditional methods for calculating sound waves propagation in an oceanic environment fail to fully address these new challenges (i.e., ray methods, normal mode methods, parabolic equation methods, and existing integral solution methods).

Recent in-situ measurements of low frequency acoustic propagation in shallow water over irregular bottom show significant differences in the received signal, depending on source frequency and location (Badiey *et al.*, 1994). Most existing theoretical or numerical methods for modeling acoustic propagation cannot address such problems. There is thus a need for a more general method of analysis for acoustic propagation in a range and depth dependent shallow water environment, with inclusion of bottom effects, that could help interpreting and understanding such observations.

2 Achieved scientific and technological objectives

As a first step towards the long term goal of the project, two simplified two-dimensional models were developed to study :

(i) The effect of abrupt or gradual changes in shallow water bottom topography on the acoustic propagation in an homogeneous water column (semi-analytical approach).

(ii) The effect of arbitrary changes in shallow water bottom topography on the acoustic propagation in an homogeneous water column (numerical Boundary Element approach (BEM); e.g. Brebbia, 1978).

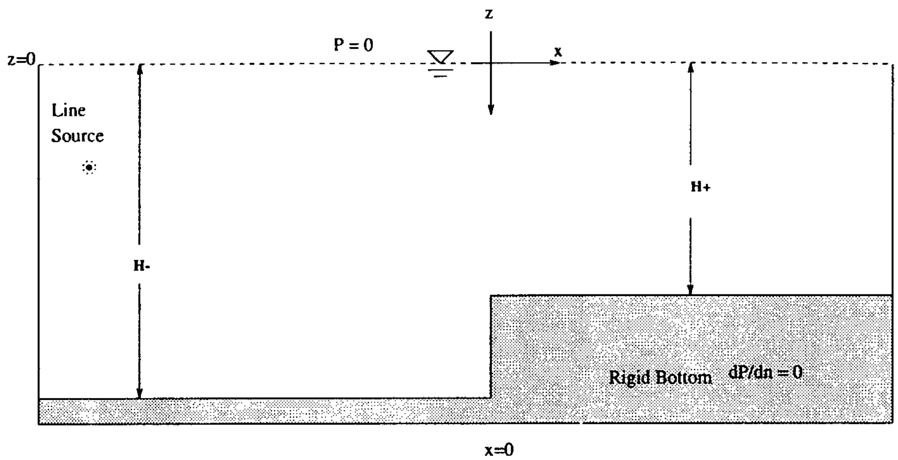

Figure 2: Typical configuration for a "step up" in the bottom.

Approach

A Boundary Integral Equation (BIE) approach was used for the representation of the solution in the water and in the bottom region (for porous bottom). Matching was specified between the solution in the interior region (water) and the exterior regions (bottom, lateral radiation regions) along interface boundaries. Eigenfunction expansions of the solution were used in radiation regions (Fig. 1). Both analytical (Green's function and eigenfunction expansion approaches) and numerical (BEM) solutions were developed for the interior problem equations, with cross-validation between both approaches.

Accomplishment and results

(i) Semi-analytical (MATLAB) solutions were developed for the acoustic propagation over simple obstacles in an otherwise flat (rigid) bottom. These were simple steps, up and down (Fig. 2), and the combinations of both into rectangular obstacles, plus plane slopes and wedges (Fig. 3). Using an impedance transfer matrix, the method can also solve problems for an arbitrary combination of steps and wedges (Fig. 4).

The solution of the problem was obtained through using both eigenfunction expansion and/or Green's function representations of the solution in subregions of the domain expressed as an impedance transfer matrix (Jensen *et al.*, 1994). These matrices were then combined, using matching conditions at interfaces between regions, to represent the solution in the whole domain.

Examples of typical results obtained using this approach are given in Fig. 5 and 6.

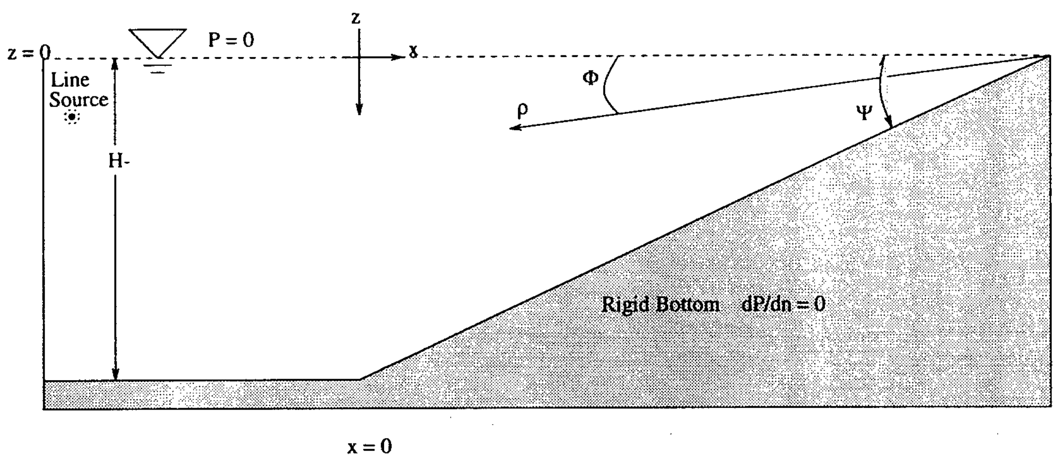

Figure 3: Typical configuration for a wedge in the bottom.

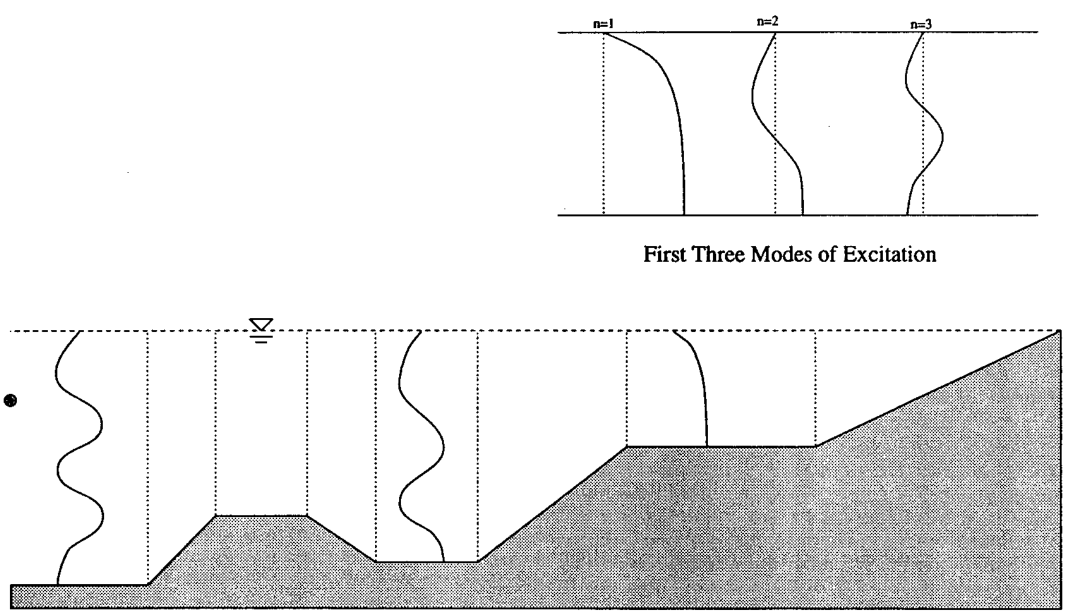

Figure 4: Typical configuration for a combination of steps, slopes and wedge in the bottom.

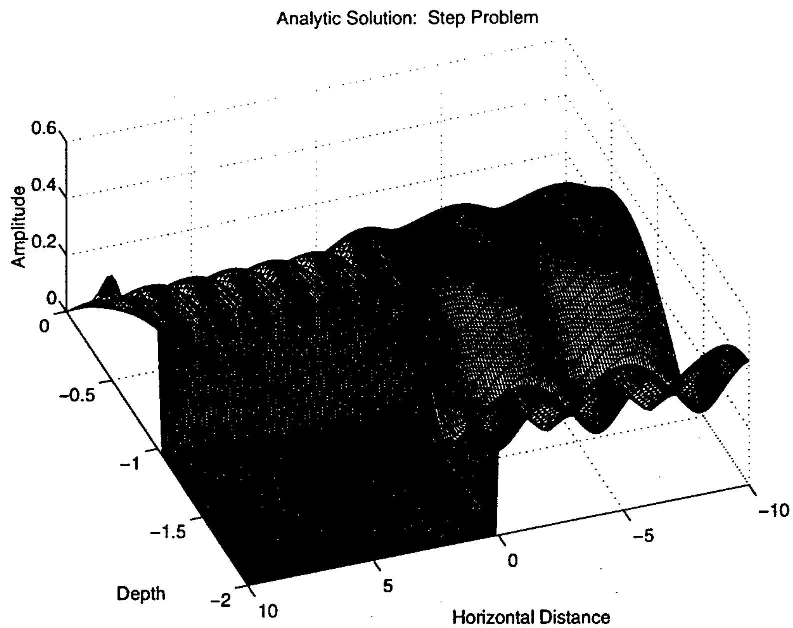

Figure 5: Example of amplitude for mode 1 for the propagation over a step similar to Fig. 2.

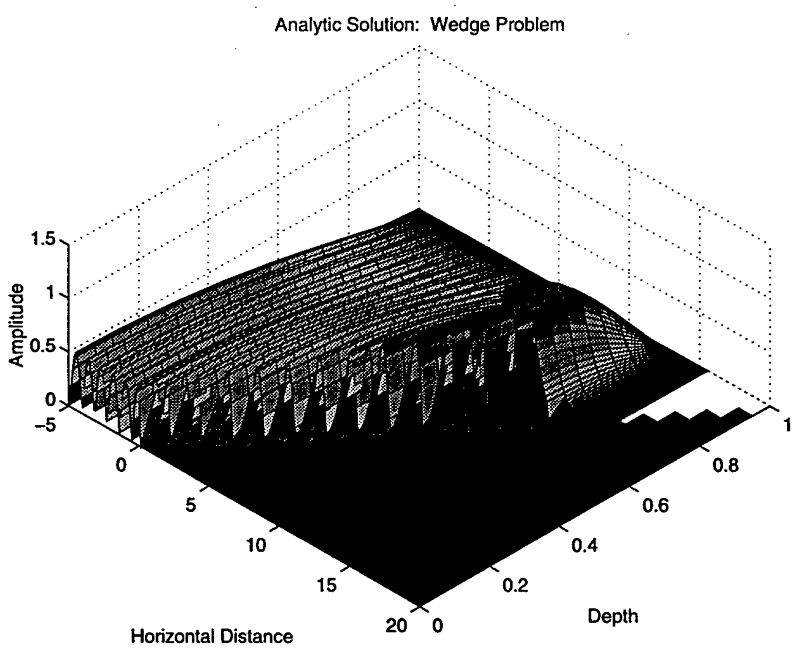

Figure 6: Example of amplitude for mode 1 for the propagation in a wedge similar to Fig. 3.

(ii) A first numerical BEM model was developed to address the same problem as in (i), but for arbitrary (rigid) bottom topography (i.e. not limited to obstacles with simple geometry).

To be able, at a later stage, to address problems with inhomogeneous water column, the Dual Reciprocity BEM approach (DR-BEM) was used to transform Helmholtz equations into Laplace's equations (Cheng *et al.* 1994; Grilli *et al.* 1995).

Consistent results were obtained for low frequency solutions but the DR-BEM method was found less accurate for higher frequency. It was thus decided to go back to a model which would still allow extension to an inhomogeneous water column but would be based on an Helmholtz equation kernel instead of a Laplace's equation. It was believed that this model would provide better results for higher frequencies.

(iii) A second numerical BEM model was thus developed to address the same problem as in (i) and (ii), based on a direct BIE solution of the Helmholtz equation, with open radiation boundaries using eigenfunction expansion representations of the radiated fields (Grilli *et al.* 1995).

Validation of the model was done for classic analytical solutions with flat bottom and the model was found to behave better than the model (ii), particularly for higher frequencies.

Many results have been obtained following this approach and further developments are still ongoing. The graduate student in charge of this project, who was supported for one year on this grant, should defend his master's degree by the end of Spring 1996 (Pedersen, 1996). His thesis will hence represent the complete exhaustive report on the present project and a copy of it will be sent to ONR in due time.

3 References

Badiey, M., Jaya, I., and Cheng, A. H-D. (1994) Shallow Water Acoustic/geoacoustic Experiment at the New Jersey Atlantic Generating Station Site. *J. Acoust. Soc. Am.* **96** (6), 3593-3604.

Brebbia, C.A. (1978) *The Boundary Element Method for Engineers.* John Wiley and Sons.

Cheng, A. H-D., Lafe, O. and Grilli, S.T. (1994) Dual Reciprocity BEM based on Global Shape Functions *Engng. Analysis with Boundary Elements* **13** (4), 303-311.

Grilli, S.T., Stepanishen, P., Pedersen, T. and Badiey, M. (1995) A hybrid DR-BEM model for underwater acoustic propagation in inhomogeneous media. Presented at the *IABEM95 Intl. Symposium* (Mauna Lani, Hawaii, August 1995).(invited paper)

Jensen, F.B., Kuperman, W.A., Porter, M.B. & Schmidt, H. (1994) *Computational Ocean Acoustics.* AIP Series in Modern Acoustics and Signal Processing. AIP Press, New York.

Pedersen, T. (1996) A hybrid BEM model for underwater acoustic propagation in inhomogeneous media. *Master's thesis.* University of Rhode Island, Department of Ocean Engineering (in preparation).